Phase Transition and Backbending in Neutron Stars

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Neutron stars have a high enough interior density as to make phase transitions in the nature of nuclear matter a distinct possibility. Examples are hyperonization, negative Bose condensation (like π^- and K^-) and quark deconfinement. According to the QCD property of asymptotic freedom, the most plausible is the quark deconfinement transition. From lattice QCD simulations, this phase transition is expected to occur in very hot ($T \sim 200$ MeV) or cold but dense matter. In this work we will use the deconfinement transition as an example [1] but in principle, any transition that is accompanied by a sufficient softening of the equation of state and occurs at or near the limiting mass star, can produce a similar signal.

Since neutron stars are born with almost the highest density that they will have in their lifetime, being very little deformed by centrifugal forces, they will possess cores of the high density phase essentially from birth if the critical density falls in the range of neutron stars. However the global properties, such as mass or size, of a slowly rotating neutron star are little effected by whether or not it has a more compressible phase in the core.

Nevertheless, it may be possible to observe the phase transition in millisecond pulsars that have been spun up to high frequency by accretion from a companion after the first part of the evolutionary phase of canonical pulsars has been completed. The observation is trivial to make—the sign of $\dot{\Omega}$. Normally the sign should be negative corresponding to loss of angular momentum by radiation. However a phase transition that occurs near or at the limiting mass star, can cause spin-up during a substantial era compared to the spin-down time of millisecond pulsars. The transition may be of either first or second order provided that it is to an appreciable more compressible phase. The reason for the spin-up as a consequence of a phase transition is that the moment of inertia is reduced by the transition of matter to a more compressible phase, and the star must spin up to conserve angular momentum.

To estimate the duration of the spin-up, we solve the deceleration equation for the star with moment of inertia having the behavior shown in Fig. 1. We find that the spin-up era lasts for 2×10^7 years. This compares with the active lifetime of a millisecond pulsar of $\sim 10^9$ years or 1/50. This is an estimate of the event rate for a trivially detectable signal. So far about 25 isolated millisecond pulsars are known.

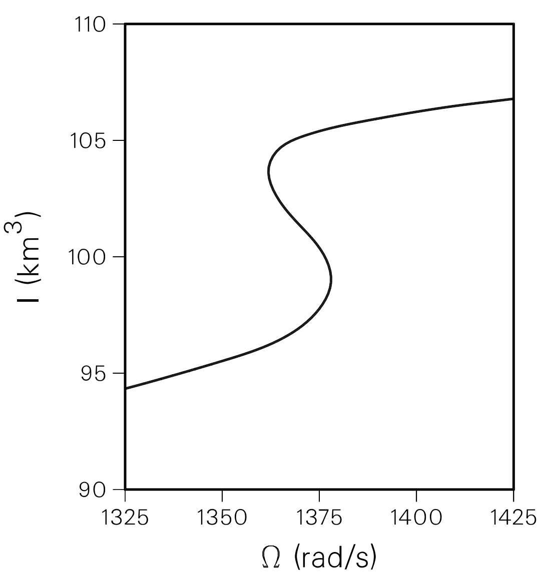

Figure 1: Moment of inertia in the region of backbending

[1] N. K. Glendenning, S. Pei and F. Weber, Phys. Rev. Lett. **79** (1997) 1603.